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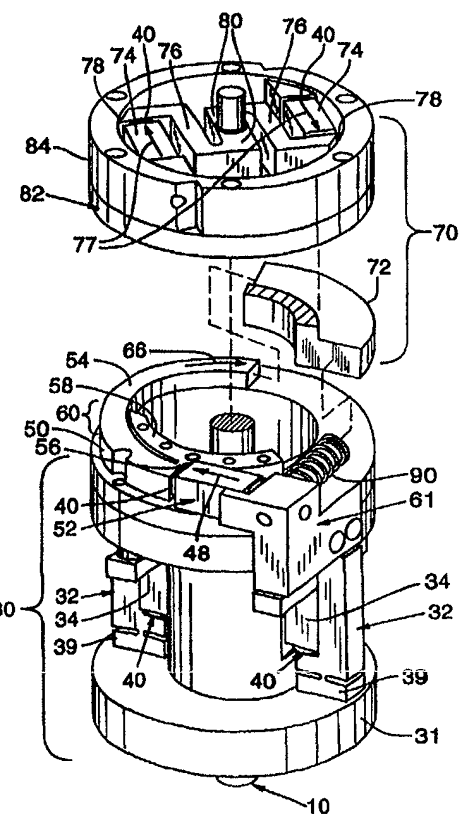
(54) Title: PIEZOELECTRIC ROTARY POSITIONER

(57) Abstract

A rotary positioner activated by piezoelectric devices is provided. The positioner has clamp, clutch, and rotational units operated in a sequence to provide bidirectional shaft rotation. In a preferred embodiment, mechanical flexures amplify the relatively small movements of linear piezoelectric devices used to operate the clamp, clutch, and rotational units.



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PIEZOELECTRIC ROTARY POSITIONER

FIELD OF THE INVENTION

This invention pertains to a rotary positioner driven by linear piezoelectric devices.

BACKGROUND AND SUMMARY OF THE INVENTION

Micropositioners using piezoelectric devices are commonly used in applications requiring precise sub-micron displacements. Representative applications include scanning tunneling microscopy and the alignment of precision optical devices. For example, linear positioners using piezoelectric devices can provide total travel of many millimeters with resolutions of less than a nanometer (nm). Such positioners are well-suited for use in optical interferometers requiring positioning accuracies of a fraction of the wavelength of light (400-700 nm). These positioners are also used in aligning laser diodes to optical fibers in which an emission region of the laser diode must be placed within a few tenths of a micron with respect to the center of a fiber.

A piezoelectric positioner is controlled by making a corresponding adjustment in an electrical drive voltage. While piezoelectric devices are readily controlled electrically and can position to sub-micron accuracies, their use in micropositioners has a number of drawbacks. A major drawback is that the piezoelectric displacements are generally quite small, even for applied voltages of hundreds of volts. This is advantageous for precise, accurate micropositioning, but it makes achievement of a wide range of motion difficult.

One way to increase piezoelectric device displacement is to combine multiple piezoelectric devices into a piezoelectric stack. The total available displacement of a piezoelectric stack is the sum of the displacements of the individual devices. For example, applying 250 V to a piezoelectric stack of about 200 individual devices produces a total displacement of less than 40 μm. Although this total displacement is 200 times greater than the displacement of an individual device, the total displacement is still too small for many applications.

Piezoelectric device displacements can also be increased using mechanical amplification. The flexure hinge mechanism is the most commonly used mechanical amplification technique for amplifying small piezoelectric displacements. Flexure hinges introduce compliance in bending about one axis while they are rigid about other axes. Under external loading, the flexure hinge acts like a pivot point and allows the relatively more rigid part of the body to rotate about this point. The geometry of the flexure mechanism determines the amplification ratio. If the flexure mechanism provides a short lever arm for the piezoelectric device and a longer lever arm for transmission of the piezoelectric displacement, the ratio of the lengths of the lever arms determines the flexure amplification.

Another drawback of piezoelectric devices is their low tolerance of shear forces. Mechanical flexure units that amplify displacements often cause shear forces on the piezoelectric

devices that drive them. These shear forces must be relieved in order to prevent piezoelectric device failure. Piezoelectric ceramics are particularly sensitive to shear forces.

The use of piezoelectric devices to generate rotary motion in a micropositioner requires the solution of additional problems. Because the most common piezoelectric devices provide only linear expansion and contraction, a rotary positioner must provide a mechanism to convert this linear motion into rotation. Piezoelectric devices that directly provide rotational motion have limited useful lifetimes due to the shear forces they encounter in generating rotation.

Various piezoelectric rotary positioners have been developed for micropositioning applications, using both linear and rotational piezoelectric devices. These positioners suffer from shortcomings such as poor torque-speed characteristics, large size, high cost, low reliability, limited movement range, and unsuitability for miniaturization.

The piezoelectric rotary positioner of the present invention overcomes these shortcomings. A piezoelectric rotary positioner according to the invention comprises a clamp unit for engaging a shaft to inhibit rotation of the shaft, a clutch unit for engaging the shaft, and a rotational unit for rotating the clutch unit. A control unit is provided for operating the clamp unit, the clutch unit, and the rotational unit. The rotational unit comprises a first piezoelectric device.

The positioner operates generally as follows. First, the clutch unit engages the shaft and the clamp unit disengages the shaft. The first piezoelectric device of the rotational unit is then controlled so that the clutch unit rotates, thereby rotating the shaft. The first piezoelectric device of the rotational unit can be selectively controlled to permit either clockwise or counter-clockwise rotation. The control unit controls the clutch unit and the rotational unit as well as controlling the clamp unit to free the shaft for rotation or to secure the shaft.

Next, the clamp unit is activated to secure the shaft in the rotated position. While the shaft is secured by the clamp unit, the clutch unit disengages and returns to its pre-rotation position. The clutch unit then engages the shaft again, the clamp unit releases the shaft, and the rotational unit rotates the shaft. This cycle repeats until the shaft has rotated through the required angle.

The small displacements of linear piezoelectric devices can be amplified by mechanical flexures. In one embodiment, the first piezoelectric device of the rotational unit is a linear piezoelectric device and the rotational unit further comprises a rotational flexure that is a section of a toroid of rectangular cross section whose axis of rotation is along the axis of the shaft. The rotational flexure thus partially wraps around the shaft. Such a rotational flexure provides a large amplification of the motion of the first piezoelectric device of the rotational unit in a compact space.

In another embodiment, the clamp unit comprises a clamp flexure, a clamp shoe, and a first clamp unit piezoelectric device. The control unit activates the first clamp unit

piezoelectric device. The motion of the first clamp unit piezoelectric device is amplified by the clamp flexure and the clamp shoe is moved to contact the shaft. In another embodiment, the clamp flexure further comprises an active axial portion directed along an axis parallel to an axis of the shaft.

In another embodiment, the clutch unit comprises a first clutch unit piezoelectric device, a clutch flexure, and a clutch shoe. The first clutch unit piezoelectric device is controlled by the control unit to selectively engage the shaft.

In other embodiments, the rotational unit further comprises a second piezoelectric device that rotates the clutch unit in a direction opposite to the rotation produced by the first piezoelectric device. In addition, the clutch unit or the clamp unit can further comprise additional piezoelectric devices and additional flexures.

The foregoing and other objects, features, and advantages of the invention will become more apparent from the following detailed description of a preferred embodiment which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an exploded, perspective view of an apparatus according to the invention which includes a clutch unit, a rotational unit, and a clamp unit.

Fig. 2 is a perspective view of the clamp unit of Fig. 1.

Fig. 3(a) is a perspective view of the rotational unit of Fig. 1. Fig. 3(b) is a perspective view of the rotational flexure of Fig. 3(a).

Fig. 4 is a block diagram of a control unit for the apparatus of Fig. 1.

Fig. 5 is a timing diagram for the electrical drive voltages for the clutch unit, the rotational unit, and the clamp unit of Fig. 1.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

For purposes of describing the preferred embodiment of the present invention, linear piezoelectric devices will be referred to as activated when an applied voltage expands the piezoelectric device. It will be apparent that an applied voltage can also be provided to contract the piezoelectric device. For convenience, the direction of piezoelectric device motion will be indicated by arrows showing the expansion direction of the piezoelectric device.

The piezoelectric devices of the preferred embodiment are multi-layer stacks manufactured by Morgan Matroc, Inc. (Bedford, Ohio). These devices are standard linear piezoelectric devices. Such multi-layer stack piezoelectric devices are readily available and provide very large blocking forces and larger displacements than a single piezoelectric layer. While other types of piezoelectric devices could be used, linear piezoelectric devices are generally less expensive and more durable.

In the preferred embodiment, all flexures are made of titanium grade-2. Titanium is used because of its desirable mechanical properties such as its high ultimate tensile stress, high modulus of elasticity, and high fatigue resistance. Titanium also has a high speed of response because of its high modulus of elasticity and low density. In addition, the high hardness of titanium is advantageous if a flexure is used as a frictional element.

With reference to Fig. 1, a preferred embodiment of a piezoelectric rotary positioner according to the invention comprises a shaft 10 that passes through, in order from the bottom of the shaft 10, a clamp unit 30, a rotational unit 60, and a clutch unit 70. The clamp unit 30 has a clamp unit housing 31 that surrounds the shaft 10. External to the clamp unit housing 31, the clamp unit 30 has piezoelectric devices 34 that contact shear plates 40 that in turn contact clamp flexures 32. It will be appreciated that clamp unit 30, the rotational unit 60, and the clutch unit 70 can be ordered differently along the shaft 10.

The rotational unit 60 is mounted adjacent to the clamp unit 30. The rotational unit 60 has a piezoelectric device holder 61 that holds a piezoelectric device 52. The piezoelectric device 52 contacts a shear plate 40 that in turn contacts a rotational flexure 50. The rotational flexure 50 comprises an active portion 54, a flexure hinge 56, and a fixed portion 58. When the piezoelectric device 52 is activated, the active portion 54 moves about the flexure hinge 56. An arrow 48 indicates the direction of motion of the piezoelectric device 52 when activated; the corresponding direction of deflection of the tip of the active portion 54 of the rotational flexure 50 is shown by an arrow 66. In the preferred embodiment, the active portion 54 and the fixed portion 58 of the rotational flexure 50 are sections of toroids of rectangular cross-section whose axes are along the axis of the shaft 10. The active portion 54 and the fixed portion 58 of the rotational flexure 50 subtend angles of approximately 180 degrees and 90 degrees, respectively, measured about the axis of the shaft 10.

The clutch unit 70 is placed adjacent to the rotational unit 60 and includes a clutch bearing unit 82 that has a clutch push extension 72. The clutch push extension 72 is a section of a toroid of rectangular cross-section placed with its axis along the axis of the shaft 10 and subtending an angle of approximately 90 degrees about the axis of the shaft 10. The clutch push extension 72 extends to contact the active portion 54 of the rotational flexure 50 on one end and a spring 90 on the other. The spring 90 presses on its other end against one surface of the piezoelectric device holder 61. Motion of the active portion 54 of the rotational flexure 50 produces a corresponding rotation of the clutch push extension 72. When the piezoelectric device 52 is activated, the active portion 54 of the rotational flexure 50 pushes the clutch push extension 72 in the direction of the arrow 66. When the piezoelectric device 52 is deactivated, the spring 90 pushes the clutch push extension 72 opposite the direction of the arrow 66 and the active portion 54 of the rotational flexure 50 moves opposite the direction of the arrow 66. Because the clutch push extension 72 is attached to the clutch bearing unit 82, motion of the clutch push extension 72 is transmitted to the clutch unit 70. In the preferred embodiment, the clutch push

extension 72 is a monolithic extension of the clutch bearing unit 82. The clutch bearing unit 82 is connected to a clutch flexure housing 84. The clutch flexure housing 84 is disc-shaped and coaxial with the axis of the shaft 10.

The clutch flexure housing 84 houses a clutch mechanism comprising two piezoelectric devices 74, two corresponding shear plates 40, and two corresponding clutch flexures 76. The two piezoelectric devices 74 contact the respective shear plates 40 that in turn contact the respective clutch flexures 76. When the piezoelectric devices 74 are activated, the piezoelectric devices 74 expand in the direction of the arrows 77. The clutch flexures 76 are monolithic extensions of the clutch flexure housing 84 and have clutch flexure hinges 78. The clutch flexures 76 have clutch shoes 80 with concave, cylindrically-shaped ends that contact the shaft 10 over a large surface area. When the piezoelectric devices 74 are activated, the clutch shoes 80 move toward the shaft 10.

Fig. 2 shows the clamp unit 30 of Fig. 1 in more detail, with the clamp unit housing 31 removed. Fig. 2 also shows the shaft 10. The clamp flexures 32 have axial portions 33 extending parallel to the axis of the shaft 10. The lower ends of the clamp flexures 32 have clamp flexure hinges 37 and clamp flexure attachments 39. The clamp flexure attachments 39 connect the clamp flexures 32 to the clamp unit housing 31, as shown in Fig. 1. The clamp flexures 32 have clamp ends 35 that extend radially toward the shaft 10 to contact clamp shoes 36. The contact ends 44 of the clamp shoes 36 are shaped to provide a large contact area with the shaft 10.

Alternatively, the shaft 10 can be provided with surfaces perpendicular to the axis of the shaft 10 such that clamp shoes can move axially to contact these surfaces and thereby inhibit the rotation of the shaft. Motion of the piezoelectric devices 34 is amplified by the clamp flexures 32. The clamp flexures 32 bend at the clamp flexure hinges 37 and the clamp flexures 32 thereby act as a lever, amplifying the motion of the piezoelectric devices 34. The amount of amplification depends on the length of the axial portions 33 of the clamp flexures 32. The axial portions 33 of the clamp flexures 32 are arranged so that the axial portions 33 extend parallel to the axis of the shaft 10, thereby permitting the axial portions 33 to be long.

In the preferred embodiment, the clamp flexures 32 provide an amplification of approximately 8, i.e., expansions of 25 μm of the clamp unit piezoelectric devices 34 produce approximately 200 μm of available displacement at the clamp ends 35 of the clamp flexures 32. The clamp ends 35 of the clamp flexures 32 generally do not move this total distance because the clamp ends 35 contact the clamp shoes 36 that in turn contact the shaft 10 before the full expansion is reached. When the piezoelectric devices 34 are activated, the clamp flexures 32 press the contact ends 44 of the clamp shoes 36 against the shaft 10 and inhibit shaft rotation.The clamp flexures 32 are arranged so that when the piezoelectric devices are deactivated, the clamp shoes 36 and the clamps ends 35 withdraw from the shaft 10.

Because the piezoelectric devices 34 produce very small displacements (typically around 25 μm), any backlash can prevent piezoelectric device expansions from being transmitted to the clamp flexures 32. In the preferred embodiment, the piezoelectric devices 34 of the clamp unit 30 are adjusted into position and optimally aligned using preloading bolts 38 and preloading beams 42, as shown in Fig. 2. To remove backlash, the preloading bolts 38 are adjusted to press against the clamp unit housing 31, shown in Fig. 1, pressing the preloading beams 42 against the piezoelectric devices 34.

Because piezoelectric devices are generally intolerant to shear forces, the preferred embodiment uses shear plates 40 to relieve the shear forces. The shear plates 40 of the clamp unit 30 transmit the piezoelectric device forces to the clamp flexures 32. The shear plates 40 each comprise a steel ball 41 held by a mounting plate 43 in a corresponding recess in the mounting plate 43 so that the steel ball 41 is free to move in the direction of the shear force. In this way, the shear force is reduced to a small frictional force that can be tolerated by the piezoelectric devices. The shear plates 40 of the clamp unit 30 are preferably oriented so that the steel balls 41 contact the clamp flexures 32 and the mounting plates 43 contact the piezoelectric devices 34. The shear plates 40 of clutch unit 70 and the rotational unit 60 are similarly oriented. It will be readily apparent to those skilled in the art that stiff rolling elements other than balls can be used.

Fig. 3(a) shows the shaft 10 and the rotational unit 60 in greater detail. The piezoelectric device holder 61 holds the piezoelectric device 52. When activated, the piezoelectric device 52 pushes against the active portion 54 of the rotational flexure 50. The rotational flexure 50 bends at the flexure hinge 56 where both the active portion 54 and the fixed portion 58 of the rotational flexure 50 join.

The rotational flexure 50 amplifies the movement of the piezoelectric device 52. In the preferred embodiment, the movement of a tip 67 of the active portion 54 of the rotational flexure 50 is approximately 12 times larger than the expansion of the piezoelectric device 52. In the preferred embodiment, the maximum expansion of the piezoelectric device 52 is approximately 25 μm and thus can produce a maximum displacement of the tip 67 of approximately 0.30 mm.

Because the active portion 54 of the rotational flexure 50 is a section of a toroid whose axis of rotation is the same as the axis of the shaft 10, the active portion 54 of the rotational flexure 50 is long and yet compact. Because the active portion 54 of the rotational flexure 50 wraps around the axis of the shaft 10, the rotational flexure 50 provides large amplifications while keeping the positioner compact.

With reference to Fig. 3(b), the active portion 54 of the rotational flexure 50 is preferably thinner than the fixed portion 58, measured parallel to the axis of the shaft 10. The active portion 54 then moves about the flexure hinge 56 without interfering with a surface or surfaces to which the fixed portion 58 is attached. It will be apparent that it is preferable that the

active portion 54 be thinner than the fixed portion 58 as measured perpendicular to a plane in which the active portion 54 moves.

It will be apparent that other shapes are also advantageous for the active portion 54 of the rotational flexure 50. Active portions that wrap around the shaft 10 effectively permit increased amplification. Effective shapes are generally follow sections of arcs or helixes that are concentric with the axis of the shaft 10. Shear forces on the piezoelectric device 52 are relieved with the shear plate 40. The deflection direction of the tip 67 of the rotational flexure 50 is shown by the arrow 66.

With reference to Fig. 1, the clutch flexure housing 84 of the clutch unit 70 contains the piezoelectric devices 74 that, when activated, push on the clutch flexures 76, causing the clutch flexures 76 to bend at the flexure hinges 78. The clutch flexures 76 amplify the approximately 25 μm expansions of the piezoelectric devices 74 of the clutch unit 70 to approximately 125 μm. Because the clutch shoes 80 of the clutch flexures 76 are pushed into contact with the shaft 10, the actual displacements of the clutch shoes 80 are somewhat smaller, limited by contact with the shaft 10. The clutch flexures 76 are arranged so that the clutch shoes 80 withdraw from the shaft 10 when the piezoelectric devices 74 are deactivated.

The tip 67 of the rotational flexure 50 pushes against the clutch flexure push wall 72, rotating the shaft 10 when the clutch is engaged. When the clutch is disengaged, the shaft 10 rotates free of the clutch unit 70.

Fig. 4 shows a schematic layout of a control unit 100. The control unit 100 preferably comprises a computer 102 that downloads program code to a driver controller 104 over a cable 103 or another medium. In the preferred embodiment, an 8-line I/O Basic Stamp I Module (BS1-IC) made by PARALLAX, Inc. (Rocklin, California) is used as the driver controller 104. The BS1-IC module is a miniature, single-board computer designed for industrial control and includes a BASIC programming language interpreter, an electrically erasable, programmable, read-only memory (EEPROM), a 4 MHz oscillator, and a 5 V regulator.

The program used to drive the piezoelectric devices of the piezoelectric rotary positioner is stored in the EEPROM of the driver controller 104. When the driver controller 104 is turned on, the BASIC interpreter reads and executes the BASIC instructions stored in the EEPROM. The computer 102 transmits the drive program to the EEPROM of the driver controller through a cable 103 using a parallel port of the computer 102. Because the computer 102 is used only to load program code into the driver controller 104, it is not needed after the code is downloaded and is consequently unnecessary for operating the piezoelectric positioner. The computer 102 does, however, permit ready reconfiguration of the sequences of voltages applied to the piezoelectric devices 34, 52, 74.

The driver controller 104 has outputs P0, P1, P2, P3, P4 for driving the piezoelectric devices 34, 52, 74. The outputs P0-P4 are delivered to a five-channel amplifier 106 via an opto-coupler 108. An amplifier 110 is one of the five amplifiers of five-channel amplifier

106; details of the other amplifiers 111-114 of the five-channel amplifier 106, which are identical to the amplifier 110, are omitted from Fig. 4 for clarity.

A single amplifier of the five-channel amplifier 106 is dedicated to each of the five piezoelectric devices 34, 52, 74 of the preferred embodiment. The opto-coupled drive signal from the output P0 is applied to the base of a transistor Q1 that controls a piezo drive transistor Q2. The output drive voltage is delivered to a piezoelectric device from amplifier outputs 115. It will be readily apparent that other amplifier designs can be used.

The clamp unit 30, the rotational unit 60, and the clutch unit 70 permit continuous, step-wise rotational positioning as follows. For purposes of describing the operation of the piezoelectric rotary positioner, it is assumed that initially the piezoelectric devices 34 of the clamp unit 30 are activated so that the clamp shoes 36 contact the shaft 10, inhibiting rotation of the shaft 10. It is further assumed that the piezoelectric devices 74 of the clutch unit 70 are not activated and the clutch shoes 80 are withdrawn from the shaft 10. Thus, the clutch unit 70 is disengaged from the shaft 10.

To begin rotation, the piezoelectric devices 74 of the clutch unit 70 are first activated so that the clutch unit 70 engages the shaft 10. Next, the piezoelectric devices 34 of the clamp unit 30 are deactivated and the clamp shoes 36 withdraw from the shaft 10. The piezoelectric device 52 of the rotational unit 60 is then activated, thereby pushing on the clutch push extension 72 and rotating the clutch unit 70. Because the clutch unit 70 has engaged the shaft 10, the shaft 10 rotates as well. When the rotational unit has reached an intended rotation (or the rotation corresponding to a maximum extension of the piezoelectric device 52), the piezoelectric devices 34 of the clamp unit 30 are activated so that the clamp unit engages the shaft 10, inhibiting rotation. The clutch unit 70 is then disengaged by deactivating the piezoelectric devices 74 and the spring 90 rotates the clutch unit 70 back to the initial position.

If a larger rotation is required, the above steps are repeated until the required rotation is achieved. Because the expansion of piezoelectric devices is limited, it is generally necessary to carry out many small rotations as described above to rotate the shaft 10 through large angles. While shaft rotations must generally be obtained with a series of small steps, the rotation is continuous in that the shaft 10 can be rotated through any angle of rotation. The rotation of the shaft 10 is therefore step-wise and continuous.

The illustrative steps above produce a clockwise shaft rotation in the direction in which the piezoelectric device 52 expands. Because the piezoelectric device 52 of the rotational unit 60 pushes in only one direction, the steps must be modified to rotate the shaft 10 counterclockwise. In order to describe the steps required to produce an opposite rotation, assume that initially the clutch unit 70 is disengaged and the clamp unit 30 inhibits rotation of the shaft 10. The piezoelectric device 52 of the rotational unit 60 is then activated, pushing on the clutch push extension 72, and rotating the clutch unit 70 clockwise. Because the clutch unit 70 is disengaged from the shaft 10, the shaft 10 does not rotate. The clutch unit 70 is then engaged

and the piezoelectric device 52 of the rotational unit 50 is deactivated. The piezoelectric devices 34 of the clamp unit 30 are then deactivated so that the clamp shoes 36 withdraw from the shaft 10, releasing the shaft 10 and thereby permitting the spring 90 to rotate the shaft 10. After the clamp unit 30 has released the shaft 10, the spring 90 presses against the clutch push extension 72 and forces the clutch unit 70 to rotate counter-clockwise. Because the clutch is engaged, the shaft 10 rotates with the clutch unit 70. As a result, a counter-clockwise rotation of the shaft 10 is achieved. Finally, the clutch is disengaged and the piezoelectric devices 34 of the clamp unit 30 are activated so that the clamp shoes 36 inhibit rotation of the shaft 10.

As described, the preferred embodiment of the invention has the piezoelectric device 52 forcing rotation in only one direction and using the spring 90 to produce an oppositely directed rotation. It will be apparent to those skilled in that art that piezoelectric pushing in both rotational directions can be readily provided.

Fig. 5 shows typical drive voltage sequences for the piezoelectric devices 34, 52, 74 for rotating the shaft 10. The relative time delays for the voltages applied to the clamp unit 30, clutch unit 70, and rotational unit 60 are shown in graphs 120, 122, and 124 respectively. T is the total drive voltage duration while τ represents the timing overlap interval between drive voltages applied to different piezoelectric devices. The timing overlap interval τ in the activation of the clamp and clutch units is provided so that the clamp unit 30 does not release until the clutch unit 70 engages, preventing the shaft 10 from rotating backwards during the transition. As can be seen from the graphs 120 and 122, voltage is applied to the clutch unit 70 a time τ before the clamp unit 30 releases the shaft 10. Similarly, as shown by the graphs 120 and 124, the rotational unit continues to push for an overlap time τ after voltage is re-applied to the clamp unit 30.

Drive voltages to the clutch unit 70 and the rotational unit 60 are coordinated so that the rotational unit 60 pushes when the clutch unit 70 is either engaged or disengaged, depending on the intended direction of rotation. While in the preferred embodiment the intervals T and τ are identical for the clamp unit 30, the clutch unit 70, and the rotational unit 60, it will be apparent that the intervals need not be identical and can be set to any desired length. It will be apparent that rotational speed of the shaft 10 can be varied by varying the frequency at which the control voltages are applied to the piezoelectric devices. It will also be apparent that a shaft encoder in communication with the control unit 100 can be provided. The shaft encoder permits the control unit 100 to determine how far the shaft 10 has rotated and adjust the rotation of the shaft 10.

The preferred embodiment of the piezoelectric rotary positioner generates high torque, but the high torque is not completely transmitted to the shaft because of the relatively lower frictional clutching and clamping torques corresponding to the clutch shoes 80 and the clamp shoes 36. No special attention has been paid to the friction surfaces in the preferred

embodiment. As will be appreciated, the transmitted torque may be increased by increasing the friction of the clutch shoes 80 and the clamp shoes 36 on the shaft 10.

While the preferred embodiment uses activated piezoelectric devices to cause the clamp unit 30 to inhibit shaft rotation, it is apparent that activated piezoelectric devices could also be arranged so that the clamp unit 30 would release the shaft when the piezoelectric devices 34 are activated. Similarly, the clutch unit 70 can be arranged so that activation of the piezoelectric devices 74 disengage the clutch from the shaft 10.

The preferred embodiment uses five piezoelectric devices but it will be apparent that fewer or more could also be used.

This embodiment has an angular resolution of about 0.25 degrees when the piezoelectric device 52 of the rotational unit 60 is driven with 240 V, depending on the rate at which it is driven. It will be apparent to those skilled in the art that the angular resolution may be increased by reducing the piezoelectric device drive voltage. Alternatively, resolution may be increased by reducing the amplification of the rotational flexure 50 by modifying either the overall geometry of the flexure mechanism or the flexure hinge.

The preferred embodiment rotates the shaft 10 either clockwise or counterclockwise and can be operated in any orientation. However, only one piezoelectric device (the piezoelectric device 52) acts to rotate the shaft 10, and it pushes in only one direction. It will be apparent that additional piezoelectric devices and rotational flexures can be added to provide piezoelectric forces in opposing directions.

While the preferred embodiment uses linear piezoelectric devices, the invention is not limited to such devices. For example, rotary piezoelectric devices that directly produce rotation are suitable.

Having illustrated and described the principles of the invention in a preferred embodiment, it should be apparent to those skilled in the art that the preferred embodiment can be modified in arrangement and detail without departing from such principles. In view of the many possible embodiments to which the principles of the invention may be applied, it should be recognized that the illustrated embodiment is only a preferred example of the invention and should not be taken as a limitation on the scope of the following claims. We claim as the invention all that comes within the scope of these claims.

We claim:

1. A piezoelectric rotary positioner for rotating a shaft, comprising:

a clamp unit for engaging the shaft and thereby inhibiting the motion of the shaft;

a clutch unit for engaging the shaft;

a rotational unit having a first piezoelectric device, the first piezoelectric device operable to rotate the clutch unit;

a control unit for operating the clamp unit, the clutch unit, and the first piezoelectric device to rotate the shaft to a desired position and secure the shaft in that position.

2. The piezoelectric rotary positioner of claim 1 wherein the first piezoelectric device is a linear piezoelectric device.

3. The piezoelectric rotary positioner of claim 1 wherein the control unit provides a drive voltage at a drive frequency to the first piezoelectric device and controls the rotation rate of the shaft by varying the drive frequency of the drive voltage.

4. The piezoelectric rotary positioner of claim 1 wherein the control unit provides the first piezoelectric device with a drive voltage having a magnitude and controls the rotation rate of the shaft by varying the magnitude of the drive voltage.

5. The piezoelectric rotary positioner of claim 1, further comprising:

a shaft encoder in communication with the control unit, for controlling the rotation of the shaft.

6. The piezoelectric rotary positioner of claim 1, further comprising a rotational flexure for amplifying the displacement of the first piezoelectric device, the rotational flexure comprising a fixed portion, an active portion, and a flexure hinge wherein the active portion of the flexure hinge is moved by the first piezoelectric device.

7. The piezoelectric rotary positioner of claim 6 wherein the rotational unit further comprises a shear plate for relieving shear forces on the first piezoelectric device, placed in contact with the first piezoelectric device and the fixed portion of the rotational flexure.

8. The piezoelectric rotary positioner of claim 6 wherein the rotational unit is external to the shaft.

9. The piezoelectric rotary positioner of claim 6 wherein the active portion of the rotational flexure is a section of a toroid whose axis is coaxial with an axis of the shaft.

10. The piezoelectric rotary positioner of claim 6 wherein the active portion of the rotational flexure is directed along a circular arc whose center is concentric with the shaft.

11. The piezoelectric rotary positioner of claim 6 wherein the active portion of the rotational flexure is thinner than the fixed portion measured perpendicular to a plane in which the active portion moves.

12. The piezoelectric rotary positioner of claim 6, wherein:

the active portion of the rotational flexure is directed along a circular arc whose center is concentric with the shaft; and

the rotational flexure is external to the shaft.

13. The piezoelectric rotary positioner of claim 6, wherein:

the active portion of the rotational flexure is directed along a circular arc whose center is concentric with the shaft; and

the first piezoelectric device is external to the shaft.

14. The piezoelectric rotary positioner of claim 6, wherein the active portion of the rotational flexure is directed along a helix whose center is concentric with the shaft.

15. The piezoelectric rotary positioner of claim 6, wherein the rotational unit further comprises a second piezoelectric device for rotating the shaft in a direction opposite to that of the first piezoelectric device.

16. The piezoelectric positioner of claim 1 wherein the clamp unit further comprises a clamp flexure, a clamp shoe, and a first clamp unit piezoelectric device, whereby a motion of the first clamp unit piezoelectric device is amplified by the clamp flexure so that the clamp shoe contacts the shaft thereby inhibiting the motion of the shaft.

17. The piezoelectric positioner of claim 16 wherein the clamp flexure further comprises an active axial portion directed along an axis parallel to the shaft, and the active axial portion of the clamp flexure is moved by the first clamp unit piezoelectric device.

18. The piezoelectric positioner of claim 17 wherein the clamp unit further comprises a shear plate for relieving shear forces on the first clamp unit piezoelectric device, the shear plate placed in contact with the first clamp unit piezoelectric device and the clamp flexure.

19. The piezoelectric rotary positioner of claim 1 wherein the clutch unit further comprises a first clutch unit piezoelectric device and a clutch shoe, whereby the first clutch unit piezoelectric device causes the clutch shoe to engage the shaft.

20. The piezoelectric rotary positioner of claim 19 wherein the clutch unit further comprises a clutch flexure, whereby the motion of the first clutch unit piezoelectric device is amplified by the clutch flexure.

21. The piezoelectric rotary positioner of claim 19 wherein the clutch unit further comprises:

a clutch flexure for amplifying the motion of the first clutch unit piezoelectric device; and

a shear plate in contact with the first clutch unit piezoelectric device and the clutch flexure for relieving shear forces on the first clutch unit piezoelectric device.

22. A method of rotating a shaft with a piezoelectric device comprising the steps of:

providing a clamp unit for engaging the shaft to inhibit the motion of the shaft, a clutch unit for engaging the shaft, a rotational unit further provided with a piezoelectric device for

rotating the clutch unit, and a control unit for operating the clamp unit, the clutch unit, and the rotational unit;

engaging the clutch with the shaft;

disengaging the clamp unit from the shaft;

controlling the piezoelectric device so that the clutch unit and the shaft rotate;

engaging the shaft with the clamp unit whereby the rotated shaft is secured.

23. The method of rotating a shaft of claim 22 further comprising the step of providing a rotational flexure exterior to the shaft, wherein the rotational flexure amplifies the motion of the piezoelectric device.

24. The method of rotating a shaft of claim 22 wherein the piezoelectric device is a linear piezoelectric device.

25. A piezoelectric rotary positioner for rotating a shaft comprising:

a clamp unit for engaging the shaft to inhibit the motion of the shaft, the clamp unit comprising a clamp shoe, a clamp flexure comprising an active axial portion directed along an axis parallel to the shaft, a first clamp unit piezoelectric device, and a shear plate in contact with the first clamp unit piezoelectric device and the clamp flexure whereby a motion of the first clamp unit piezoelectric device is transmitted by the shear plate and amplified by the clamp flexure so that the active axial portion moves, causing the clamp shoe to contact the shaft thereby inhibiting the motion of the shaft;

a clutch unit for engaging the shaft, the clutch unit comprising a first clutch unit piezoelectric device, a clutch shoe, a clutch flexure, and a shear plate, whereby the motion of the first clutch unit piezoelectric device is transmitted by the shear plate to the clutch flexure, amplified by the clutch flexure, and causes the clutch shoe to engage the shaft;

a rotational unit external to the shaft for rotating the clutch unit, the rotational unit comprising a first linear piezoelectric device, a rotational flexure external to the shaft for amplifying the displacements of the first piezoelectric device, the rotational flexure comprising a fixed portion, an active portion that is a section of a toroid whose axis is coaxial with an axis of the shaft, and a flexure hinge, and a shear plate and wherein the active portion of the flexure hinge is moved by the motion of the first linear piezoelectric device against the shear plate; and

a control unit for operating the clamp unit, the clutch unit, and the rotational unit to rotate the shaft to a desired position and secure the shaft in that position.

FIG. 1

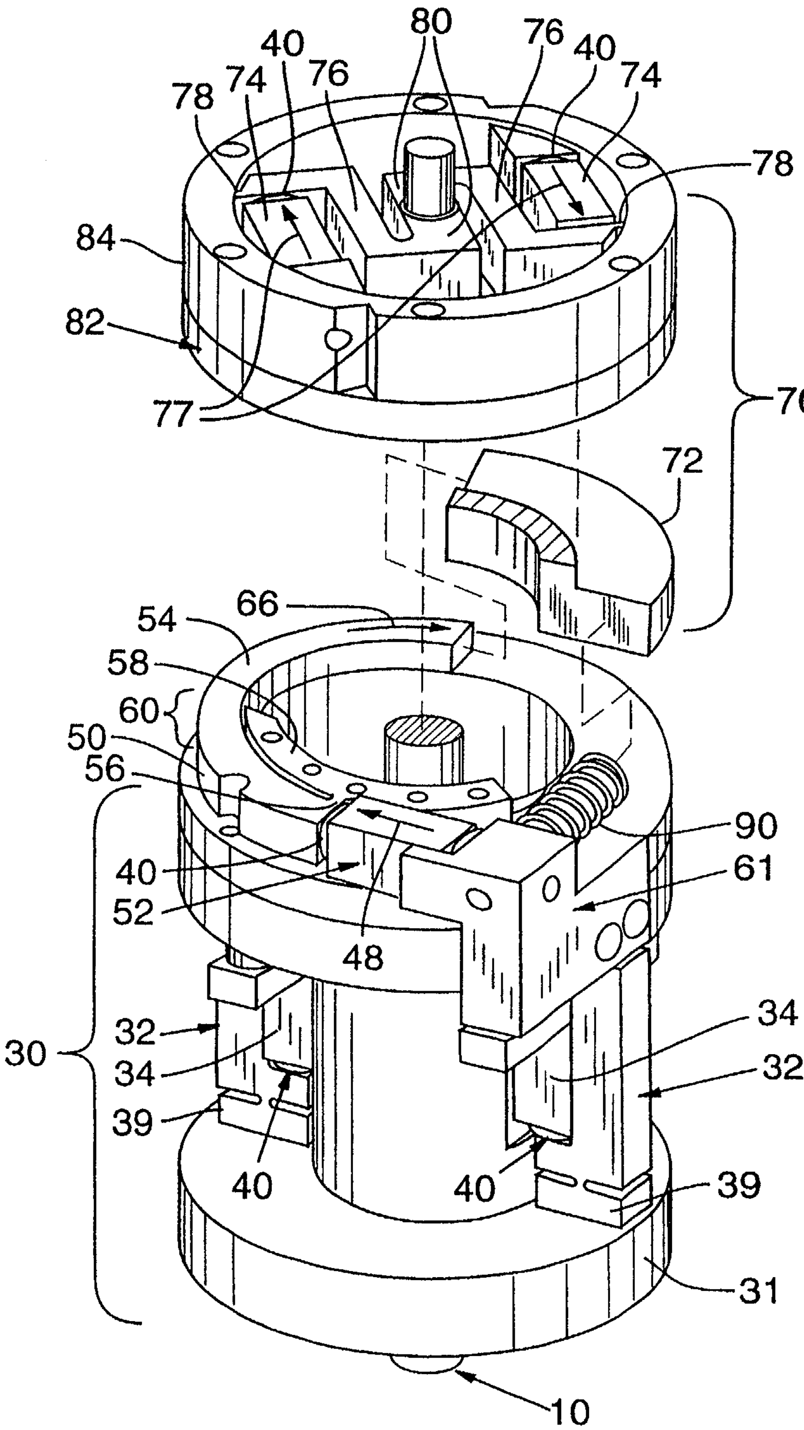
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FIG. 2

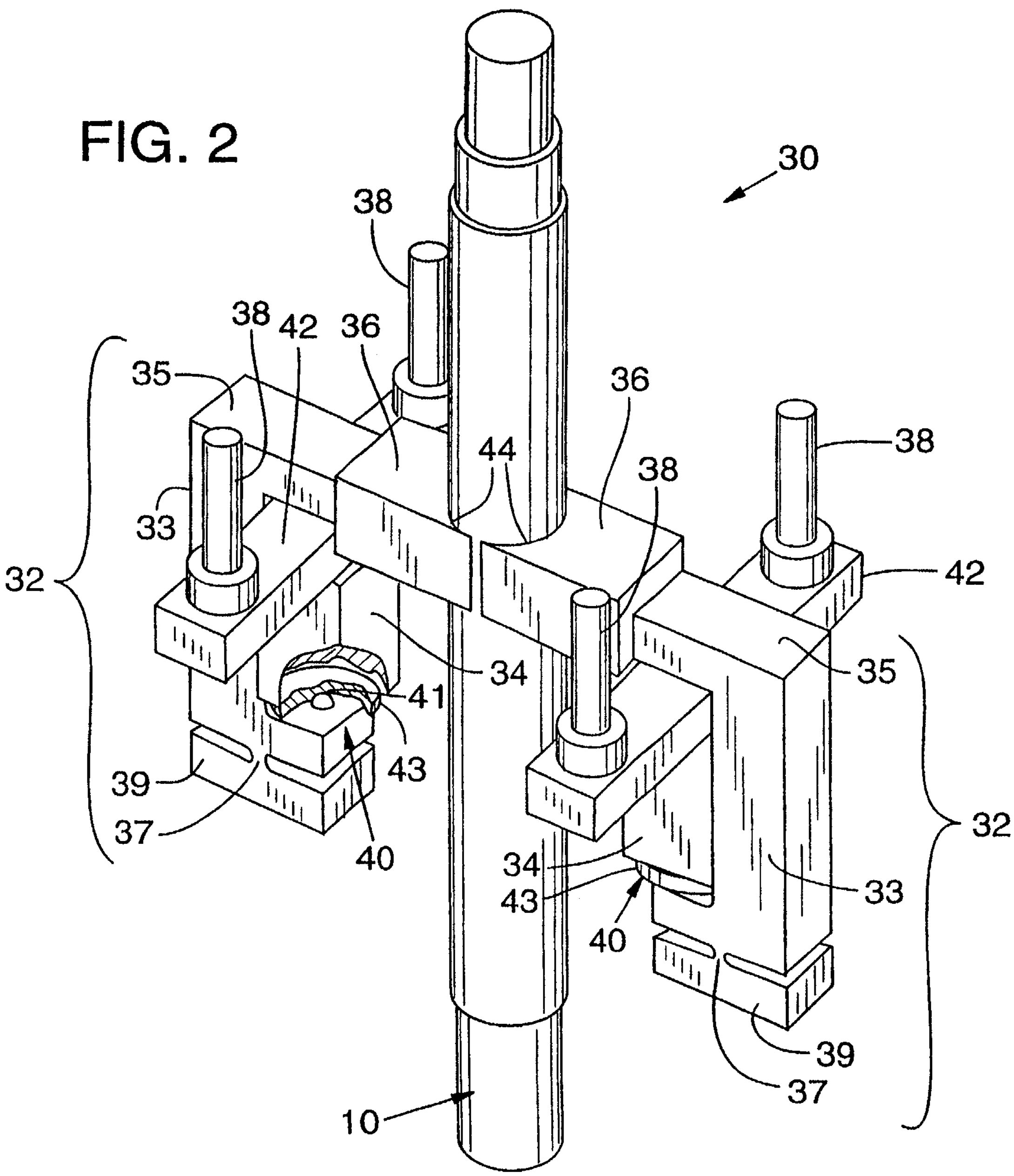
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FIG. 3(a)

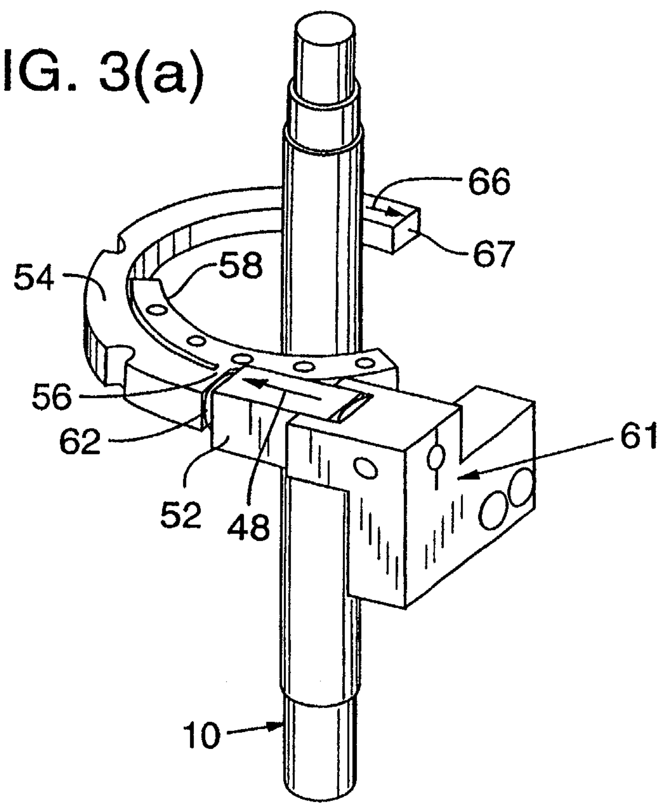


FIG. 3(b)

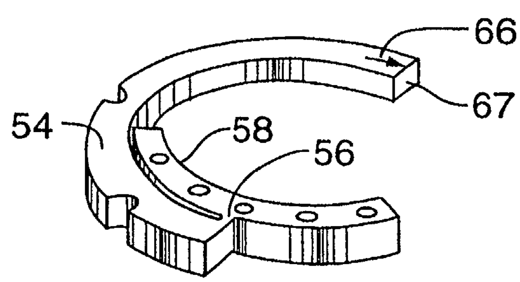
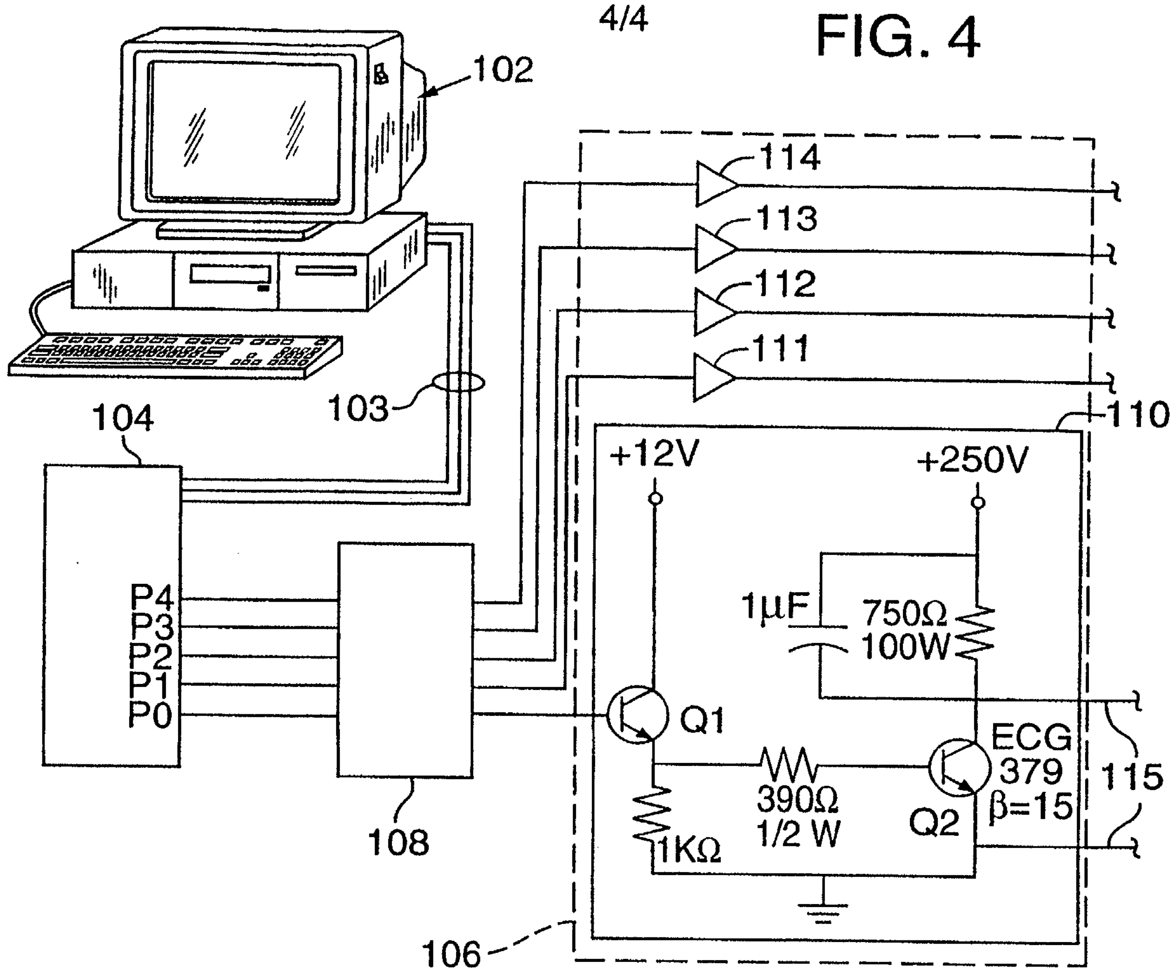


FIG. 4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Q2
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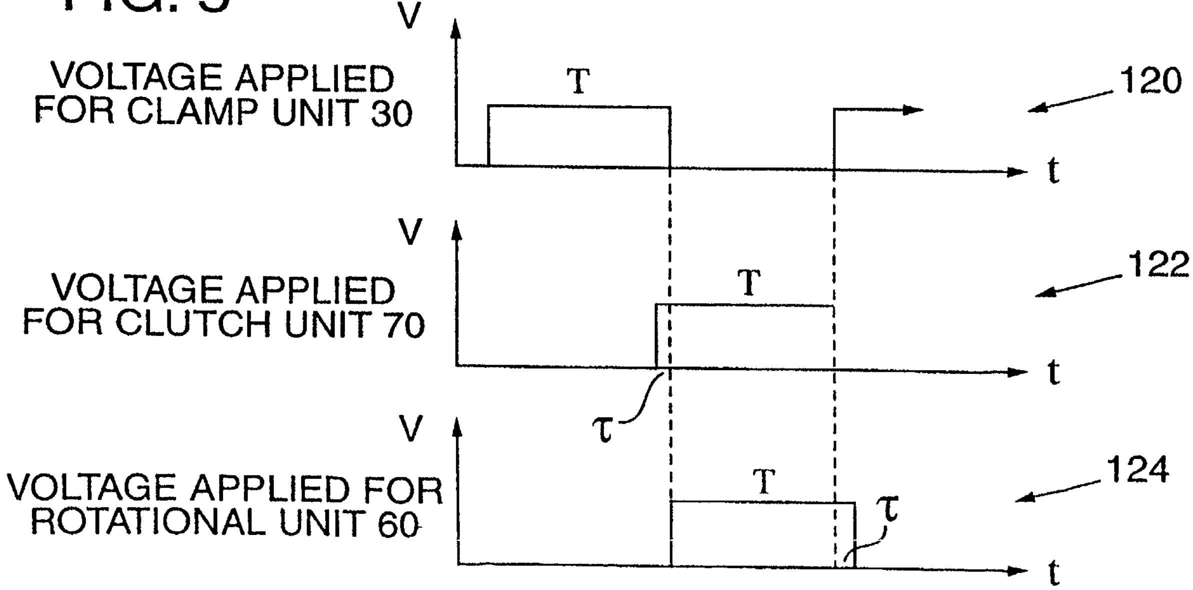
FIG. 5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INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 97/00787

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L41/09

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 009, no. 225 (E-342), 11 September 1985 & JP 60 082072 A (NIPPON DENSHI KK), 10 May 1985, see abstract ---	1
X	PATENT ABSTRACTS OF JAPAN vol. 009, no. 110 (E-314), 15 May 1985 & JP 60 002081 A (MATSUSHITA DENKI SANGYO KK), 8 January 1985, see abstract ---	1
X	PATENT ABSTRACTS OF JAPAN vol. 009, no. 027 (E-294), 6 February 1985 & JP 59 172981 A (HITACHI SEISAKUSHO KK), 29 September 1984, see abstract ---	1

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
4 February 1998	12/02/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Int ational Application No
PCT/CA 97/00787

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 013, no. 192 (E-753), 9 May 1989 & JP 01 012878 A (HITACHI METALS LTD), 17 January 1989, see abstract ---	1
X	WO 91 09428 A (TELDIX GMBH) 27 June 1991 see page 3, paragraph 1 -----	1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte ..tional Application No
PCT/CA 97/00787

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9109428 A	27-06-91	AT 121565 T	15-05-95
		DE 4038020 A	20-06-91
		DE 59008950 D	24-05-95
		EP 0505386 A	30-09-92
		US 5264755 A	23-11-93